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A description of the organization, content, evaluation, and possible modification of an experimental interdisciplinary course in the honors program at the University of Michigan. The course was taught by a physicist, an astronomer, a geologist, and a biologist. It was "designed to introduce the gifted non-science student to the types of thinking common to these sciences and to the inter-relations among them. It is not a survey course. Each scientist rigorously develops in depth those theories in his own field that contribute to a central theme which unites the course. The theme chosen was *Evolutionary Processes*, tracing in particular the evolution of stars, the solar system, the earth, and life on the earth. This report discusses the organization and content evaluation by students and staff, and possible modifications of the course which has been developed."

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HE 7383

an experimental interdisciplinary course in science for gifted non-science majors*

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INTRODUCTION

Within the past few years science courses in liberal arts colleges have been undergoing re-evaluation. Since science and technology have become increasingly important in modern life, all educated individuals should have some basis for evaluating continuing developments in science.

In 1958 we were given the opportunity to develop a one-semester science course for sophomore non-science majors in the recently introduced Honors Program at The University of Michigan. Since the non-science major has a very limited contact with science, we tried to make maximum use of this contact. We agreed that a course for non-science majors based upon a sound understanding of a few underlying principles, developed rigorously, is superior to a survey course. No single course can convey a thorough knowledge of one science, much less of several sciences. However, certain scientific insights lend themselves to thorough developments from first principles without loss of rigor. Examples of such achievements can be found in all well-developed sciences. We feel that, for such a one-semester course, comprehension of these insights provides the best basis for appreciating current scientific developments. By appreciation of scientific developments, we mean the ability to understand the processes involved in scientific discovery to the extent of anticipating the next step.

Rather than confine the content of the course to a single scientific field, we have established an experimental interdisciplinary course. This four-credit-hour course is currently taught by a physicist, an astronomer, a geologist and a biologist, each of whom is actively engaged in research. It is designed to introduce the gifted non-science student to the types of thinking common to these sciences and to the inter-relations among them. It is not a survey course. Each scientist rigorously develops in depth those theories in his own field that contribute to a central theme which unites the course. The theme chosen was *Evolutionary Processes,* tracing in particular the evolution of stars, the solar system, the earth and life on the earth. This report discusses the organization and content, evaluation by students and staff, and possible modifications of the course which has been developed. Our experience with this course may be helpful in designing similar programs in the future.

*This report was made possible in part by funds granted by the Carnegie Corporation of New York. That corporation is not, however, the author, owner, publisher or proprietor and is not to be understood as approving by its grant any of the statements or views expressed herein.

See an earlier statement by Professor Slobodkin on the interdisciplinary approach in science in the SUPERIOR STUDENT (November, 1958) 11.

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ORGANIZATION AND CONTENT

Class lectures were given four times each week and were supplemented by less formal evening discussion sessions about once every three weeks. Generally, all four lecturers were present in class and at the evening sessions. The course was divided into a four-part sequence. Each lecturer delivered an uninterrupted series of from twelve to fifteen lectures, arranging his material in such a way as to assure continuity with the following lecturer.

The initial series of lectures was given by the physicist. He developed the fundamental physical concepts with which the remaining three lecturers could develop the central theme. In this section he started with crude experimental observations of motion and introduced the kinematical concepts needed to describe them unambiguously. Next came the more abstract concepts of mass and force which led to the formulation of laws governing motion. These were followed, at a more rapid rate, by other fundamental principles governing the behavior of mechanical, thermodynamic, electromagnetic, optical, atomic and nuclear phenomena, which would be assumed in the material presented by subsequent lecturers. The limitations, as well as the realm of applicability of theories explaining physical processes were emphasized. Demonstrations were presented wherever possible.

Using some of the physical concepts introduced, the astronomer oriented the class to his material by describing the content of the observable universe (i.e., stellar and interstellar matter, the general description of a galaxy and the clustering of galaxies). He then proceeded to a discussion of the quantities which can be regarded as "direct observables" (e.g., positions, brightnesses and spectra of stars). He then followed this presentation with a very rigorous discussion of the means by which such "indirect observables" as a star's mass, intrinsic luminosity, radius and chemical composition can be determined from the "direct observables". At this point, the students had the necessary background to begin the central theme of the course—evolution. After discussing the different possible types of universe (e.g., expanding, contracting, pulsating and steady-state), the astronomer proceeded to a discussion of the observational tests to which these possibilities can be subjected. Theories concerning the formation of galactic systems and groups of stars were presented and the evolution of individual stars was treated both from the theoretical and empirical points of view. Finally, the sun's life cycle was discussed, after which the origin of the sun was tied into the origin of the planetary system and consequently with the origin of the earth.

Starting with the proto-planet developed by the astronomer, the geologist surveyed the anatomy of the earth indicating the mineralogy, compositon and structure of its external crust and the probable structure and composition of its internal layers. He then developed the present concepts of the evolutionary processes causing changes in this anatomy throughout geologic time. Involved here were the processes of uplift, mountain-building, continental drift and the evolution of landforms through erosional processes. The concepts of geologic time, relative and absolute, were considered at length to illustrate the effectiveness of gradual earth processes when operating over immense spans of time and also to provide a time-setting for the development of life subsequently considered by the biologist.

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The biologist presented the taxonomic and zoo-geographic data used by Darwin and Wallace, and developed the evolutionary theory initially in Darwinian terms. He then discussed the refinements of Darwinian evolution that have developed from recent advances in genetics and ecology. In genetics, particular emphasis was placed on population genetics and polygenic systems. Ecological information centered mainly on competition theory. Having established the theoretical necessity of evolution and, therefore, the necessity for the existence of some initial organism, he concluded the course with a summary of current theories of the origin of life. Emphasis was placed on the mechanism of evolution rather than on the history of life on earth.

Questions from both students and faculty played an important role in the course. During class, questions were permitted at the discretion of each individual lecturer. The questions which pertained directly to the lecture material were answered in class; any questions which would have required excessive digression by the lecturer were deferred for later discussion at an evening session. There was a general understanding that all questions were worthy of discussion, either immediately or in evening discussion. Occasionally questions arose which were not in the strict field of competence of the current lecturer. These questions were answered by the staff member best informed on that particular question.

An examination was given at the end of each of the four lecture sequences by the lecturer whose sequence had just been completed. As a result the four examinations were somewhat different in character. They ranged from true-false and multiple choice questions to problems, essay questions and a take-home examination. Examples of examination questions may be found in the Appendix.* Some questions on the take-home examination required the students to read original material published in professional journals. The performance of the students was essentially independent of the type of examination given.

The evening sessions were surprisingly effective supplements to the course. Although attendance was voluntary, at least eighty percent of the students were present at each evening meeting. When the staff felt that enough questions had accumulated to warrant an evening session, we arranged a date that was acceptable to all the staff members and to as many of the students as possible. Since the evening sessions lasted three or four hours, we arranged to meet in the comfortable surroundings of a dormitory lounge. Early in each evening meeting, answers were given to questions which had arisen during the formal class session but which had been deferred for lack of time. Later in the evening, more general discussion ensued.

At the end of the course a four-part final examination was given. Each staff member wrote and graded his own portion of it.

EVALUATION OF THE COURSE

After offering the course twice, we have certain definite impressions about its character and some of its possibly unique features. The students have also expressed their impressions to us, either in conversation or in anonymous critiques written in response to questions circulated both by us and by the University.

*See below, page 8.

The students reacted variously to the lack of a text. Some appreciated the opportunity to engage in varied reading. Others felt somewhat lost because they could not have a single text for reference.

All students were remarkably enthusiastic, and they seemed particularly pleased with the opportunity for close, informal association with staff members.

A small minority felt that the course went too fast, but in general the response concerning the pace was very favorable.

The majority of students indicated that by having four sciences taught in an integrated course, they were led to an appreciation of the inter-relationships among the disciplines and the transferability of ideas, not only between the scientific disciplines but between science in general and other fields of scholarship.

Most of the students emphasized the value of active discussion and differences in viewpoint which often arose among the four staff members. It became apparent, particularly during the evening sessions, that considerable effort was required by the staff as well as the students in order to grasp new concepts. This demonstrated two things: first, that many important ideas do not come easily; second, that the popular image of the omniscient scientist is a fiction.

The following remarks by the staff are concerned with some of the difficulties in carrying out our original plans. As indicated in the Introduction, one of our main aims in this course was to develop the students' comprehension of scientific insights. Our measure of success was the extent to which each student was able to anticipate the next step in the development of scientific concepts. Since the student's comprehension is indicated by his questions and comments, we thought it desirable to allow frequent interruptions during lectures. However, questions often tended to divert the class into channels other than those considered profitable by the lecturer at the time. Although common to many college courses, this problem was more acute in this course because of the high caliber of students and the fact that the lecturers were always receptive to questions. We anticipated the conflict between the lecturer's desire to answer questions and his intention to complete his lecture sequence on time, by leaving ten of the sixty class hours unprogrammed. These ten hours were kept in reserve to be used as needed to compensate for lecture time used in discussion. It turned out that the ten hours were just adequate. Each lecturer did indeed use a portion of this time. We think that the difficulty is an inescapable element in such a course.

Normally, each lecturer's vocabulary tended to include the specialized terminology and jargon characteristic of his field (e.g., cross-over distance, homologous stars, fermions, magna). The frequent discussions and debate, however, often compelled him to reformulate his remarks in simple English. In addition, penetrating questions sometimes required him to retrace his arguments all the way back to first principles, an effort profitable to both student and teacher ("Why is it meaningless to refer to 'the heat in a body'?" "How are similar species distinguished?").

The interdisciplinary character of the course was especially profitable to each staff member, for it enabled him to see familiar concepts applied by his colleagues in fields less familiar to him than his own. Moreover, the students profited by seeing a given concept applied to systems in different sciences. For example, the concept of entropy developed in physics reappeared with additional subtleties when applied to biological systems.

The most significant accomplishment, from our point of view, was the visible growth of the students' familiarity, understanding and competence in the use of fundamental principles. The students' questions were of much higher caliber than those arising in other undergraduate classes. ("In radiocarbon dating, how do you know that cosmic bombardment has been constant throughout geologic time?") The students' performance on examinations was superior to that of non-Honors students in introductory and beginning intermediate courses in science. (Many examination questions were borrowed from conventional course examinations, and the average grades were about twenty percent higher.)

POSSIBLE MODIFICATIONS

At the time of this writing, this course has been given twice. Both times it has been regarded as an experiment, at least in part. (Indeed, the first time the course was given, it was supported as an experiment by a grant from the Carnegie Corporation.) We think that the experiment has been successful and we expect to repeat the course in its present form. We realize, nevertheless, that such a program is more expensive than most undergraduate courses in terms of the student-to-staff ratio. (It is roughly four times as expensive as conventional courses at the University of Michigan.) We regard this expense as justified, although certain changes in the interest of economy may be necessary either here or at other institutions that may be considering a similar program.

In the following paragraphs we list our opinions on the desirability of six possible modifications:

1. Increase the number of subjects and lectures. We regard this as inadvisable. The first time the course was taught, five lecturers participated. They did not have sufficient time to develop adequately all necessary concepts. (Any attempt to go beyond five instructors would be an altogether different program from ours, rather than a modification.)

2. Decrease the number of lecturers. This is the least objectionable way to economize. The same range of material could be covered, with some change in emphasis, by two or three of the lecturers with at least one physical scientist and one natural scientist participating. However, the gain in economy is largely offset by the decrease of stimulating interaction among the lecturers and by the loss of depth and rigor in the subject matter.

3. Decrease the range of subjects presented. A course in *Evolutionary Processes* would suffer equally from the deletion of any one of the four disciplines. If physics were deleted, the other disciplines would need to introduce superficial analogies of the physical principles which they apply; if either astronomy or geology were not included continuity would be lost; if zoology were omitted, the most fascinating (non-physical) evolutionary concept, the origin and development of life, would be lost, and this now constitutes the climax of the course. On the other hand, a course of comparable quality might be designed around a different central theme which would require only three staff members. We feel that the advantages of an interdisciplinary course would be essentially lost with less than three lecturers.

4. Open the course to non-Honors students. In view of the depth and rigor with which the material is explored, the pace is too rapid for understanding and

retention in one semester by non-Honors students at the University of Michigan. On the other hand, two semesters devoted to the same material would probably be suitable for average students.

5. Offer the course to science majors. There is a strong likelihood that science majors (including non-Honors students) would profit from the interdisciplinary character of this course.

6. Increase or decrease the enrollment. We feel that the optimum student-to-staff ratio for a course of this nature is approximately 7:1. Decreasing the enrollment below about ten would be inefficient from the standpoint of effective teaching; increasing the enrollment over approximately forty would result in an undesirable decrease in opportunity for direct communication between individuals in the class and between individuals and lecturers.

Naturally, readers from other institutions will encounter other situations which we have not anticipated and, of course, they may need to adopt procedures different from those we have outlined here. Nevertheless, we hope that our experience may help in designing similar courses elsewhere, since we are convinced that they can be vastly superior to the prevailing versions of science education available to non-specialists in science.

APPENDIX: EXAMINATION QUESTIONS

Astronomy

(1) Contrast the explosive (big-bang) and steady-state universes in the following respects:

(a) Change of mean density with time.

(b) The reason why the density of galaxies does or does not appear to change systematically with distance.

(c) Imagine that you are looking at a very large volume of space anywhere in the universe. Contrast what you would see *now* with what you would see 10^{12} years from now if you live in an explosive (big-bang) universe as opposed to a steady-state universe.

(d) The fate of each type of universe.

(2) You have just been asked to derive the mass and luminosity for each of two stars in a visual binary system in order to plot them on the mass-luminosity relation. Both stars are easily observable separately and have moderately large proper motions in the sky. Describe what "direct observables" you will need and explain in an orderly, step-by-step account the procedure which you will follow in obtaining each star's:

(a) mass

(b) luminosity

Zoology

(1) A possible objection to the theory of evolution in its modern form is that many structures seem adept only in finished or half-finished form and could not have evolved by small steps. Why is this in disagreement with modern evolutionary theory? How do you answer the argument?

(2) Prove, by citing appropriate evidence and experiments, that hereditary material is particulate.

(3) The following four gene sequences have been reported on the 11th chromosome of Hairy Woozles (Wouzelius pubescens):

(a) EFGAJIHBCDKL

(b) ABCDEFGHIJKL

(c) DCBAEFGHIJKL

(d) AGFEJIHBCDKL

There is believed to exist (or have existed) a fifth gene sequence. This sequence must be (or must have been):

(e).....

The five gene sequences must be related to each other, evolutionarily, by the following relation (in which double arrows represent possible ancestral relations):

Physics

Show how simultaneity depends on the frame of reference of the observer, according to the Special Theory of Relativity. Describe a situation in which two reliable observers would disagree about the simultaneity of two events which they both observe.

Geology

(1) How might the following physical and geological concepts be associated?

(a) Convection currents in a cooling fluid *AND* intrusion of igneous rocks.

(b) $T = K\sqrt{L/g}$ and the crust of the earth.

(c) Half-life and the geologic time scale.

(d) Transverse or shear waves and the core of the earth.

(e) Archimedes Principle and mountain roots.

(f) Refraction and the "shadow zone."

(g) Density and salt domes.

(h) $F = K m_1 m_2/d^2$ and continental drift.

(2) Indicate whether the following statements are true or false:

(a) The contraction theory of mountain building does not explain the geographic distribution of mountain chains satisfactorily.

(b) Convection current theory depends on the fact that rocks are very poor conductors of heat.

(c) If a beam of continuous x-rays is passed through a stationary single crystal, then every set of atomic planes will give a reflection.

(d) Sedimentary rocks tend to thin as they are traced into mountainous regions.

(e) The recording of weak primary p-waves in the shadow zone is probably due to the presence of an inner solid core within the earth.

science for non-science majors

By **John Palfrey**, Dean
Columbia College

C. P. Snow has described the gulf between the cultures of science and the humanities. It is a gulf that is first created by neglect in primary schools, consolidated in high school and made largely unbridgeable in college, and is unbridgeable thereafter. The bridge, if it is to exist, has got to be built at the start. Science will not be the foreign, forbidding, impersonal subject it is to many an English major, if, in the next generation, every student is exposed to it as a central part of his early school experience and has it to get to know as an area for his natural curiosity.

With such a beginning, few students will reach college age with this sense of gulf between the cultures, and without some training or feel for the natural sciences. At that point, colleges can successfully provide an education in the liberal arts that includes explorations *in* science as well as *about* it, and an adult consideration of its place as part of our knowledge, our philosophy, our history, our politics and our future.*

While waiting for this development to occur, the colleges must nevertheless try to assimilate the new science into the liberal arts curriculum.**

The reason for many of the perplexities experienced by colleges in working out a science program, particularly for those not majoring in science, is that colleges have not defined sharply enough what they would like and are best equipped to accomplish. Most of them require courses in science for every undergraduate, and hope for the best. These requirements vary widely, but they tend to fall into one of two categories: required introductory courses in two or more fields of science, or else one or more general education courses in science.

Columbia College has followed the

*The preceding paragraphs are from an address delivered to the Columbia Associates, April 27, 1960.
The remainder of this discussion of the science curriculum is from **The College at Columbia University: Extracts from the report of the Dean of Columbia College for 1959, pages 3-5.

first of these approaches, despite its affinity for general education, after a series of experiments with "general" science courses in the late thirties and early forties, which were not continued after the war. The College, however, has not been fully satisfied with its present practice of requiring all students to take courses in two of the three categories in which the science courses are grouped.

However well planned and taught, many of these offerings have inherent limitations. Students are usually not provided with the personal experience of doing laboratory work and gaining at least a sense of method and approach to the subject. The courses are generally designed for those not going on in the field, who therefore are never exposed to the enthusiasm and talents of future scientists. Thereafter, the College, having provided this necessarily simplified introduction to a science, does nothing more about it. Students are not called upon to go a step further in any one field, or to relate it to any other area of science or to any outside subject with which they are familiar, or to consider scientific knowledge in the broader context of contemporary civilization.

The second approach of liberal arts colleges is to require students to take "general" science courses, also designed mainly for the non-scientist, which are difficult to teach meaningfully without the foundation which the first approach seeks to provide. These courses, presented as a sequential introduction to a number of sciences, or as representative case studies in science, are designed to give the student a sense of what science is about and of its place in the scheme of things. Usually these courses are concerned with the broad reaches of the sciences, in an historical or philosophic context.

Such courses have been tried at Columbia, but have been regarded by its science departments as an unsatisfactory way of introducing science to a non-scientist. They are regarded as courses *about* science—in general education, in history and in philosophy—but not as courses *in* science.

The dilemma of the liberal arts colleges is that they generally find time in their curriculum to provide only one type of offering for the non-scientist, and yet would like to do two things at once—to make all those with a liberal education literate in mathematics and at least one science, and at the same time to make them aware of science's broader implications in the world today. It seems to me that a liberal arts college should concentrate more on the second of these aims, but in order to make it feasible should expect more and demand more of the secondary schools to do the first, and assist them in achieving it. The schools are better equipped, in sciences as in foreign languages, to provide the foundations and the tools for higher learning. A first-rate course in high school physics would have what a college course is likely to lack: small classes, laboratory work, and the enlivening presence of future scientists.

If the student body as a whole arrived at college thus equipped, literate in science and with grounding in mathematics, and then had this training consolidated in the freshman year, the science departments would feel quite differently about offering, perhaps requiring, courses in the philosophy or history of science, or participating in seminars about science and society.

Furthermore, these could become courses of importance for science majors as well. In addition to their specialities, such students would be concerned with the foreign relations of physics or chemistry or biology, asked to think philo-